Effect of Irrigation Practices Upon the Nitrogen Metabolism of Sugar Beets

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Satisfactory explanations for the wide variations in yield of sugar beets are frequently not possible. This is especially true of yields ranging from 20 to 35 tons per acre. Sugar beets showing no signs of disease, with full stands, proper cultivation, grown on productive soils, given optimum fertilizer and grown under similar climatic conditions, produce harvested yields which vary from 10 to 15 tons per acre and 3 to 4 percentage units of sucrose. Comparable data does not exist for glutamic acid, but in a small series of tests where glutamic acid measurements have been made values from 0.05 to 0.5 percent are reasonably common.

Insufficient attention has been given to the influence of soil moisture conditions, and method of irrigation on yield and quality of sugar beets. Marcum, et. al. (8)[3] obtained soil moisture differences but could not demonstrate yield differences. Nuckols (11) obtained significant yield differences for various soil moisture conditions one year, but no differences the second year. Doneen (2) concluded that sugar beets were not responsive to soil moisture conditions. Haddock and Kelley (5) and Haddock (6) obtained marked differences in yield among four soil moisture conditions studied and Archibald and Haddock (1) showed that method of irrigation as well as soil moisture condition markedly influenced yield and quality of sugar beets.

It would be of value to know the cause of these conflicting results.' Are they due to the balancing of growth factors which operate in opposing directions, or are the effects of soil moisture conditions so small that differences are difficult to measure, or do climatic factors overshadow the effects of soil moisture conditions?

In the present study a more direct and complete measure of nitrogen response under varying soil moisture conditions has been made possible by the inclusion of data on the glutamic acid content of the beet. The utilization of yield, sucrose and glutamic acid data for the calculation of discriminant functions which maximize differences between treatments permits a numerical evaluation of environmental effects not otherwise possible.

Discriminant functions suitable for measurement of the difference between two classes have been applied to a wide variety of problems among which are the classification of *Iris* spp. by R. A. Fisher (4), identification of races of *Drosophila pseudo-obscura* by Mather and Dobzhansky (9) and the selection of breeding stock in wheat by H. Fairfield Smith (12). Mather (10) gives an excellent treatment of their derivation and use.

Experimental Procedure

The data presented in this paper were obtained from an experiment on irrigation and soil management of crops in rotation at Logan, Utah.[4]

[1] The authors are indebted to Dr. J. L. Haddock, Division of Soil Management and Irrigation Agriculture, USDA in cooperation with the Utah Agricultural Experiment Station who supplied us with the samples for glutamic acid determinations. The basic data on yield of sugar beets, sucrose percentage of beets, fertilizer and irrigation data is his. We wish to express our appreciation to Dr. Haddock for his cooperation and interest in this study and for his assistance in the preparation of the manuscript.

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[3] Numbers in parentheses refer to literature cited.

[4] Part of a study under Research and Marketing Act of 1946 with 11 Western States, Alaska and Hawaii cooperating with U. S. Department of Agriculture (Project W-9).

The complete report of the 1950 results is to be found elsewhere (7). The portion referred to in this paper has to do with the effect of two types of irrigation, four soil moisture conditions and two levels of nitrogen fertilizer on the yield, sucrose percentage, glutamic acid content and nitrogen status of sugar beets.

Each of the four replications was divided into eight sub-blocks for purposes of testing the effects of the two types of irrigation (sprinkler vs. furrow) and four soil moisture conditions described in Table 1. Superimposed upon each irrigation soil moisture block were eight fertilizer plots described in Table 2.

Table 1.—Irrigation and Soil Moisture Description and Symbols.

Irrigation Symbols[1]	Soil Moisture Level and Symbol	Description of Treatment
		Irrigation when soil moisture content in root zone
1F and 1S	High tension plots low moisture (WJ)	Near permanent wilting or about 8 atmospheres tension as shown by gypsum blocks. (Total of five S or four F irrigations)
2F and 2S	Medium-high tension medium-low moisture (W_2)	At 1/3 available soil moisture remaining or about 4 atmospheres tension as shown by gypsum blocks. (Total of six S or six F irrigations)
3F and 3S	Medium-low tension medium-high moisture (W_3)	At 2/3 available soil moisture remaining or about 0.6 atmospheres tension as shown by tensiometers. (Total of eleven S or nine F irrigations)
4F and 4S	Low tension high-moisture (W_4)	Near field capacity or 0.2 atmospheres tension as shown by tensiometers. (Total of fourteen S or twenty-two F irrigations)

[1]F = Furrow irrigation; S = Sprinkler irrigation by Perf-O-Rain pipe-

All information on fertilizer treatments except nitrogen was averaged out.[5] Average data for sucrose, weight and glutamic acid (geometric mean) are shown in Table 3. The discussion has been divided into:

1. The results derived from information within sub-blocks, viz., the nitrogen response and its changes with irrigation practice.
2. The results derived from information between sub-blocks, viz., effects of irrigation connected with nitrogen changes, and those independent of nitrogen.

Effects of Nitrogen

The yield of beets and sugar as affected by nitrogen fertilizer showed a significant variation from block to block, hence 21 D.F. are available for measurements of the confidence limits for responses to nitrogen as shown in Table 3. The yield of beets and the increase in glutamic acid content of beets in response to nitrogen fertilization increase, with increasing supply of water. On the other hand, sucrose is decreased when nitrogen is added to the soil. This depression in sucrose as influenced by nitrogen fertilization is lessened with increasing water supply.

The data in Table 3 may be used to contrast the influence of nitrogen on yield of beets, glutamic acid content and sucrose percentage under furrow vs. sprinkler irrigation. It will be observed that, as soil moisture increases under both furrow and sprinkler irrigation, nitrogen fertilizer increasingly

[5] Pulp samples for glutamic acid determinations were composited from four fertilizer plots on each irrigation—soil moisture plot. Thus two 10-beet samples were obtained from each of the two plots receiving no treatment and composited with a similar sample from each of two plots receiving phosphorus only. This no-nitrogen plot sample was a composite of 80 beets. The pulp sample for plots receiving 80 pounds of nitrogen was also a composite of 80 beets.

stimulates, yields of beets and glutamic acid content of beets. This effect is more pronounced under furrow than under sprinkler irrigation. Sucrose percentage is conversely affected by soil moisture condition as well as by method of irrigation. Whereas it appears as though these differences are closely related to the greater quantity of water supplied to the soil by furrow than by sprinkler irrigation, some other explanation must be found to satisfy the differences between soil moisture level 1 and 2. Sprinkler irrigation required approximately the same quantities of water as furrow at these levels. This is not to say that some deep percolation and loss of soil nitrogen did not occur under furrow irrigation at soil moisture level 2. The data on glutamic acid and sucrose percentage indicate that the nitrogen status was better under sprinkler than furrow irrigation and hence that some nitrogen may have been lost to sugar beets, or at least was rendered less available under furrow irrigation.

Table 2.—Fertilizer Symbols and Treatments.

Fertilizer Symbol	**Number of plots**	**Fertilizer Treatments[1]** (acre **basis)**
O	2	No treatment.
P	2	100 pounds of P_2O_5 per acre as treble superphosphate.
N	2	80 pounds of nitrogen per acre as ammonium sulfate.
NP	2	100 pounds of P_2O_5; 80 pounds of nitrogen.

[1] Drilled on soil surface April 14, sugar beets planted May 1, 1950.

Table 3.—Effect of Varying Soil Moisture Conditions upon Nitrogen Response in Sugar Beets.

Tons Beets per Acre

Soil Moisture	Furrow N = 0	Furrow N = 80	Furrow Diff.[1]	Sprinkler N = 0	Sprinkler N = 80	Sprinkler Diff.[1]
W1	13.9	14.6	0.7	15.7	14.7	—1.1
W2	17.8	19.3	1.5	16.4	17.5	1.1
W3	16.0	19.8	3.8	21.1	19.9	—1.1
W4	14.5	20.8	6.3	18.1	20.1	2.0

LSD (5%) of Niitrogen Difference 2.6

% Sucrose

Soil Moisture	Furrow N = 0	Furrow N = 80	Furrow Diff.[1]	Sprinkler N = 0	Sprinkler N = 80	Sprinkler Diff.[1]
W1	16.7	15.6	1.1	16.5	15.4	1.1
W2	17.2	16.9	0.3	16.7	16.1	0.6
W3	17.6	17.4	0.1	16.9	16.2	0.7
W4	17.3	17.3	0	17.0	16.7	0.3

LSD (5%) of Nitrogen Difference 0.5

% Glutamic Acid

Soil Moisture	Furrow N = 0	Furrow N = 80	Furrow Diff.[1]	Sprinkler N = 0	Sprinkler N — 80	Sprinkler Diff.[1]
W1	.12	.24	91%	.18	.27	44%
W2	.08	.19	148%	.15	.24	59%
W3	.06	.16	179%	.14	.26	80%
W4	.04	.16	280%	.07	.19	166%

LSD (5%) of Nitrogen Difference 33%

Nitrogen Status

Soil Moisture	Furrow N = 0	Furrow N = 80	Furrow Diff.[1]	Sprinkler N = 0	Sprinkler N = 80	Sprinkler Diff.[1]
W1	359	451	92	394	465	72
W2	293	375	82	370	429	59
W3	258	339	81	349	424	76
W4	246	342	96	295	384	89

LSD (5%) of Nitrogen Difference 23

[1] Nitrogen Response.

- Arrangement: Randomized split plot design, four replications. Harvest area per sample: four plots of three 24-foot rows. Sample size: 80 beets; 20 beets each from four plots. Planted May 1, 1950. Harvested October 21, 1950.

In order to examine the relationships among the various factors in Table 3 consider the following data from a study of sugar type and yield type of beets.

	% Sucrose	% Glutamic Acid	Tons Per Acre
Yield type	16.1	.158	17.4
Sugar type	17.1	.205	13.4

Here glutamic acid rises with sucrose, yield decreases with increasing sucrose, and with increasing glutamic acid. This will be referred to as a + — — correlation pattern (r_{SG} , r_{sw} , r_{GW}) . Had the glutamic acid of the first crop been 0.40 instead of 0.15 the correlation pattern would be — — + and it might be asserted with considerable confidence that the first crop had been able to obtain more nitrogen than the second (14) .

The analysis of variance shown *in* Table 4 compares the average size of the various nitrogen responses to their overall error. Inclusion of the significant interactions *in* the error reduces the effect of nitrogen on weight. Nitrogen has its usual — — + correlation pattern, but its error has a strongly marked + + + pattern. When highly significant correlations such as this occur, it is possible to take advantage of them by calculating a discriminant function (10) which is a linear compound of the three measured values percent sucrose (S) , 3 + log percent glutamic acid (G) , and ton beets per acre (W) which gives the greatest possible significance to the effect of nitrogen. If one constructs a three dimensional graph of the results, the discriminant shows the direction of measurement in space giving the greatest significance. The coefficients b^S, b^G, and b^W of S, G, and W respectively in the discriminant function are calculated by a solution of the equations

$$b^S A_{SS} + b^G A_{SG} + b^W A_{SW} = a_{SS}$$

$$b^S A_{SG} + b^G A_{GG} + b^W A_{GW} = a_{GG}$$

$$b^S A_{SW} + b^G A_{GW} + b^W A_{GW} = a_{WW}$$

where A_{ss}, A_{SG}, etc., are the mean squares for error of S, the mean cross product for error of SG, etc. (or any set of values proportional to such mean squares and cross products), and $a_{ss,}$ a_{GG}, and a_{ww} the corresponding root mean squares (on 1 D.F.) for nitrogen (or any set of proportional values) . This gives a discriminant function

$$Y' = b^S s + b^G G + b^W W$$

as the quantity maximizing the significance of the nitrogen difference. Ordinarily it is convenient to choose one of the measurements as a basis for comparison by giving it an arbitrary coefficient— ± I or ± 10. In the present case

$$Y = b^G Y'/1O = (10\ b^S /b^G)S + 10G + (10b^W ./b^G) W.$$

The analysis of variance in Table 4 gives

$$Y= —1.92S + 10G — .115W. \qquad \text{Eq. 1}$$

It is convenient to choose the coefficient of G arbitrarily as 10. In order to avoid negative values of Y and to give a standard form comparable between experiments, it is also convenient to make the equation formally equivalent to 10 (3 + log % GA) at 15 percent sugar and 25 tons per acre by adding the constant 1.92(15) + .115(25) = 31.68:

$$Y = -1.92S + 10G - .115W + 31.68 \qquad \text{Eq. 2}$$

The quantity Y is referred to as the *nitrogen status:* it is the most sensitive available measure of differences *in* the effect of applied nitrogen. Although generally of the form given, the coefficient of S has been found to vary in other experiments[6] from +0.7 to —3.1 and that of W from +0.6 to —0.4, representing the change from extremely low nitrogen (so low that added nitrogen tends to increase sugar) to extremely high nitrogen (so high that added nitrogen actively depresses yield). In variety trials at a single level of nitrogen, this discriminant has frequently been found by maximizing block or environmental differences. Theoretical implications of the nitrogen status and of other discriminants calculated have been discussed elsewhere (13). Changes *in* the direction of Y measured *in* this experiment would produce — + — correlation patterns characteristic of changes at a higher nitrogen level than the — — +. Under the extreme conditions above, nitrogen produces a + + + pattern. The increase in accuracy afforded by the use of this discriminant can be judged from the increase in F values shown in Table 4. A further measure of the increase in sensitivity and uniformity of response is given by the assumption, for comparative purposes, that each irrigation method gave equally spaced water levels. This permits the calculations of the following F values based on 26 degrees of freedom:

	DF	S	G	W	Y
Nitrogen	1	**45.1**	**297.4**	**13.3**	**549.8**
Interaction with Method	1	**4.2**	**17.4**	**9.9**	**n.s.**
Interaction with Water Levels	1	**16.9**	**25.7**	**10.3**	**8.3**
Interaction with Blocks	1	**10.8**	**n.s.**	**3.3**	**n.s.**

Interactions are removed or greatly reduced, and the nitrogen status discriminant gives nearly twice as much information about nitrogen differences as the best single measurement, glutamic acid.

Accordingly, it seems appropriate to use the nitrogen status as a biological assay of the relative amounts of nitrogen available to the sugar beet. The average change in Y with 80 lbs. N was 4.24; the equation may be calibrated in terms of lb. N/acre (applied before planting) by multiplying eq. 2 by the factor 80/4.24:

$$\text{Nitrogen Status} = -36S + 190G - 2.1W + 594 \qquad \text{Eq. 3}$$

Nitrogen status as estimated by eq. 3 gives a measure of the nitrogen applied of 80 ± 8 lbs. Average values of the nitrogen status calculated for each treatment are given in Table 3. The general level of the nitrogen status is arbitrary, only the differences have significance.

Effect of Irrigation on Nitrogen Status

Average values over both nitrogen levels and their appropriate confidence intervals (5 percent points on 21 D.F.) are given in Table 5. It is of interest that the results on furrow irrigation for percent sucrose, yield of beets and gross yield of sugar reproduce those of Doneen (3) quite pre-

[6] Unpublished data International Minerals & Chemical Corporation.

cisely. Sprinkler irrigation gave an increasing yield up to a higher water level (best at 24.5) than did furrow irrigation (best at 17.8 in.). The optimum crop tends to be better under sprinkler irrigation, but not significantly so.

The data on glutamic acid show a strong decline with increasing water. This was also confirmed by a corresponding effect on many of the other nitrogenous components of the beet.[7] This result is diametrically opposed to that of Doneen (2) who found no difference in nitrogen content over a similar range of irrigation treatments. This is evidently attributable to a wide difference in leaching or other nitrogen loss in the two soils.

Table 4.

Mean Squares and Mean Cross Products

	DF	S^2	G^2	W^2	SG	SW	GW	Y^2
Error	31	0.36742	.030258	11.924	+.070762	1.5162	.48160	497.99
N	1	8.8726	5.7538	87.450	—5.7711	—27.855	18.118	207676

F Values

S	G	W	Y
24.15[b]	124.06[b]	7.33[a]	417.03[b]

Correlation Coefficients

SG	SW	GW
+.67[b]	+.72[b]	+.80[b]

[a] It is significant at 5% point.
[b] It is significant at 0.1% point.

Application of the nitrogen status discriminant to the sub-block data indicates still more significant differences. Sprinkler irrigation left beets with a highly significantly greater nitrogen status: 56 ± 24 lb., on the average. At the optimum water level the difference must be even greater —at least 70 lb. On the average sprinkler irrigation caused a reduction in nitrogen status of 3.9 ± 2.1 lb. N. per inch water, while the average reduction for the lower three furrow irrigations was 7.1 ± 3.6 lb. N per inch water applied. The increase from 28 to 64 inches of water in the highest soil moisture level of furrow irrigation caused no further reduction in the nitrogen status.

Irrigation Effects Independent of Nitrogen

In an attempt to discover what, if any, significant effects might be shown by the irrigation level, other than that of reduction of nitrogen status, the nitrogen status equation 1 was expressed in units of the standard deviation *(s)* , the square root of mean square for error Table 4 corresponding to the 31 D.F. for error from which equation 1 was calculated. This gives:

$$Y = -1.16S' + 1.74G' - 0.40W \qquad \text{Eq. 4}$$

where $S' = S/s_s = S/\sqrt{0.36742}$ and $G' = G/s$ and $W = W/s$

The coefficients of this equation express the relative contributions of the three measured variables to information about nitrogen status. Secondary discriminant functions, which maximized the significance of effects *perpendicular* to equation 4, were calculated (13) . Six such discriminants maximizing the differences between adjacent water levels for each irrigation were calculated. The only discriminant even approaching significance was that between the second and third water levels of sprinkler irrigation, but the one between the first and second level indicated the same direction of measurement. Therefore, the biggest difference between water levels perpendicular

[7] Unpublished data Haddock and Linton.

to the nitrogen status discriminant should be given by maximizing the difference between the first and third levels of sprinkler irrigation. Expressing the results in terms formally equivalent to tons of beets at 15 percent sucrose and 0.15 percent glutamic acid, equation 5 was obtained:

$$Z = 3.5S + 13G + W - 80.8 \qquad \text{Eq. 5}$$

This discriminant, in this case showing the major effect of water level **not** associated with changes in nitrogen status, has been previously identified (13) with various other genetic and environmental changes and has been called the *growth potential.* Being an increasing function of both sucrose

Table 5.—Effects of Furrow and Sprinkler Irrigations after Averaging Values at Both Nitrogen Levels.

Soil Moisture	Inches Water Applied		Tons Beets		% Sucrose		Tons Sugar	
	F	S	F	S	F	S	F	S
W1	15.6	17.0	14.29	15.19	16.11	15.98	2.30	2.43
W2	17.8	18.9	18.56	16.91	17.08	16.38	3.17	2.77
W3	28.0	24.5	17.89	20.50	17.49	16.53	3.13	3.39
W4	64.3	57.6	17.66	19.09	17.28	16.84	3.05	3.21
LSD (5%)			2.9		0.71			

Soil Moisture	% GA		Nitrogen Status		Growth Potential		Storage Potential	
	F	S	F	S	F	S	F	S
W1	.17	.22	405	429	19	21	17.9	17.8
W2	.12	.19	334	400	25	23	17.9	17.8
W3	.09	.19	298	386	24	27	18.3	17.4
W4	.08	.12	294	339	22	24	18.0	17.6
LSD (5%)	45%		47		5		0.6	

and weight, it is closely related to the measure of gross sugar per acre, and appears to be the best available measure of total vigor, or energy production, of the beet crop. In the present experiment, with beets at an adequate nitrogen level, the chief role of glutamic acid in the equation is to correct for the large changes which variations in nitrogen can make in sucrose content without resulting in weight changes. In experiments at deficient nitrogen levels, the coefficient of G becomes negative.

Values of the growth potential are shown in Table 5. Although the results seem quite similar to the tonnage data, the measurement is actually made at a 41° angle with the W axis. The effect of water is to first raise and then lower the growth potential—tending to raise and then lower weight, sucrose and glutamic acid in the same direction, if nitrogen changes are avoided. Growth potential changes produce a + + + correlation pattern at this nitrogen level and a — + — pattern at lower nitrogen levels.

Residual Variation

The function measuring variation perpendicular to both nitrogen status and growth potential is:

$$X = S + 1.6G - 0.16W + 0.5 \qquad \text{Eq. 6}$$

expressed in terms formally equivalent to percent sucrose at 25 tons per acre and 0.15 percent glutamic acid. This function has been previously found by maximizing differences between sugar beet varieties and is called the *storage potential.* In the present experiment it is a major component of the environmental differences. If the assumption of equally spaced water levels is again made for comparative purposes, the following F values based on 25 D.F. between sub-blocks are obtained:

	DF	S	G	W	X	Y	Z
Irrigation Method	1	10.8	25.8	n.s.	7.8	23.6	n.s.
Water Level (Linear)	1	19.0	29.5	14.8	n.s.	40.1	5.0
Curvature in Water Effect	1	3.5	n.s.	7.1	n.s.	n.s.	7.5
Blocks	3	8.9	12.0	n.s.	14.8	33.5	n.s.

It can be seen that the bulk of information of the experiment is traceable to one cause: variations in nitrogen. All remaining variation caused by water level is accounted for on the basis of an independent factor, the growth potential, which appears to measure the rise and fall of energy output of the beet. All remaining variation of irrigation method and environment, on the other hand, is caused by a third independent factor, the storage potential, which appears to measure the distribution of energy between growth and storage. Changes in the direction of the storage potential equation tend to produce a + - - correlation pattern.

It is interesting that the four possible correlation patterns referred to in this discussion are all represented. Naturally the error variation of most experiments is a composite of many sources of variation, so that frequently one or more of the three correlations becomes non-significant. When a single source of variation predominates, one of the following patterns appears:

Pattern r_{SG}	r_{SW}	r_{GW}	Caused by Changes in	Condition
−	−	+	Nitrogen Status	Low Nitrogen
+	−	−	Storage Potential	Any Nitrogen
−	+	−	Nitrogen Status	High Nitrogen
			Growth Potential	Low Nitrogen
+	+	+	Growth Potential	High Nitrogen
			Nitrogen Status	Extremely Low or High Nitrogen

Further work may permit further differentiation of the latter two patterns on the basis of the size of regression coefficients involved.

Summary

1. A method for measuring changes in nitrogen status has been presented.

2. Application of this method to an irrigation experiment showed that large losses of available nitrogen can be caused by irrigation even under fairly dry moisture conditions.

3. Losses in nitrogen are greatly reduced by the use of sprinkler irrigation. Savings of 56 lbs. N per acre or more are effected.

4. Residual effects of water are measured by and explained on the basis of growth potential. Increasing growth potential tends to give a concurrent increase of yield, sucrose content and glutamic acid content.

5. The concepts of nitrogen status, growth potential, and storage potential are used to explain the occurrence of four correlation patterns of sugar beets.

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